NASA-CR-200285

Title:

Stellar/Solar Convection Simulations

Grant Number:

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Principle Investigator:

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Institution:

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Annual Report:

Period: February 1994 to February 1996

Objective:

Our primary objective is to understand convection in the solar envelope: its role in transporting energy and angular momentum, in generating the solar magnetic field, in providing energy to heat the solar chromosphere and corona, in exciting p-mode oscillations and in modifying their resonant frequencies. A secondary objective is to elucidate the interaction between convection, magnetic fields and shear flow in accretion disks.

Approach:

We solve the equations of mass, momentum and energy conservation, the induction equation and the equation for LTE radiative transfer. We use a third order leapfrog predictor corrector in time and calculate spatial derivatives using third and sixth order fits to the functions.

Accomplishments:

We have developed codes in FORTRAN 77 and FORTRAN 90 to efficiently simulate compressible convection on parallel and vector computers and the visualization tools needed to analyze the results. The f77 code was benchmarked on the Cray C90, SGI (75 Mhz) Power Challenge, and Convex C3880. The F90 code was benchmarked on a CM5 and IBM SP-2.

Benchmark Results

Computer:	C90	CM5	SGI	SGI	SGI	SP2	C3880	C3880
Number Processors:	1	256	1	4	8	16	1	8
F77 Code (Mflops)	330		34	117	148*		41	268
F90 Code (Mflops):	400	3,500**				500		

*Problem is 2D interpolation routine that uses cache badly

**Since the benchmark a new set of template procedures for the derivatives and interpolations was tested at twice the previous speed.

We performed realistic simulations of convection near the solar surface on a grid of $253 \times 253 \times 163$ with a grid size of 25 km horizontally and 15-35 km vertically. The best observational resolution obtainable from the ground corresponds to about 10 grid zones. The energetics are essentially the same as at lower resolution. The granulation shows more small scale structure and is in much better agreement with observations than for simulations at lower resolution. The most dramatic effect of increasing the resolution is the increase in vorticity (figure 1). However, increasing the resolution does not significantly alter the buoyancy driving or energy transport properties of the convection.

We started relaxing to thermal equilibrium a model representing the deep layers of the solar convection zone. We reduce the thermal relaxation time by increasing the energy flux and radiative conductivity. Near the surface, where the radiative flux is negligible, the kinetic energy flux is much smaller than the enthalpy flux. At greater depths, where the radiative flux becomes comparable in magnitude to the enthalpy flux, the kinetic energy flux increases and becomes comparable to the enthalpy flux in the downdrafts (but in the opposite direction). The entropy fluctuations decrease rapidly with depth and the mean entropy gradient actually becomes stable inside the convection zone because of the transfer of energy from radiative to the convective transport (figure 2).

We simulated the nonlinear evolution of stratified, magnetized Keplerian disks. The Balbus-Hawley shear instability generates turbulence in the disk. The resulting flows regenerate a magnetic field by taping energy from the shear flow. A large scale toroidal magnetic field is generated, in the form of toroidal flux tubes with lengths comparable to the toroidal extent of the simulation domain. The magnetic energy exceeds the kinetic energy of the turbulence by a factor of 3-10. Thus, the system acts like a dynamo that generates its own turbulence. The large scale magnetic field is quasi-cyclic, reversing its direction on a timescale of about 30 orbits.

Significance:

Understanding the effects of convection on p-modes will improve our ability to probe the solar interior using helioseismology. Storage of magnetic flux below the convection zone and diffusion of flux at the solar surface are important ingredients in the solar cycle dynamo, which influences the Earth's weather and ozone layer. Transport of angular momentum and mixing into the stable interior effects the evolution of stars.

Status/Plans:

We will add a magnetic field to a snapshot of surface hydrodynamic convection and study magneto-convection: the interaction of the magnetic field, the convection, and the p-modes. We will impose a differential rotation on our deep convection simulations and investigate its possible role in producing large scale toroidal magnetic flux concentrations at the bottom of the convection zone.

Publications:

- "Dynamo Generated Turbulence and Large Scale Magnetic Fields in a Keplerian Shear Flow", (Brandenburg, A., Nordlund, Å., Stein, R.F., Torkelsson, U.), Astrophys. J., **446**, 777, (1995).
- "The Disk Accretion Rate for Dynamo Generated Turbulence", (Brandenburg, A., Nordlund, Å., Stein, R.F., Torkelsson, U.), Astrophys. J. Let. **458**, L45 (1996).
- "Convection: Significance for Stellar Structure and Evolution", (Nordlund, Å. and Stein, R. F.), in *Stellar Evolution: What Should be Done:* 32nd Liege Int. Astroph. Coll., eds. (in press).
- "Turbulent Viscosity in Accretion Discs", (Torkelsson, U., Brandenburg, A., Nordlund, Å., Stein, R.F.), Astrophys. Let. & Comm., (submitted).

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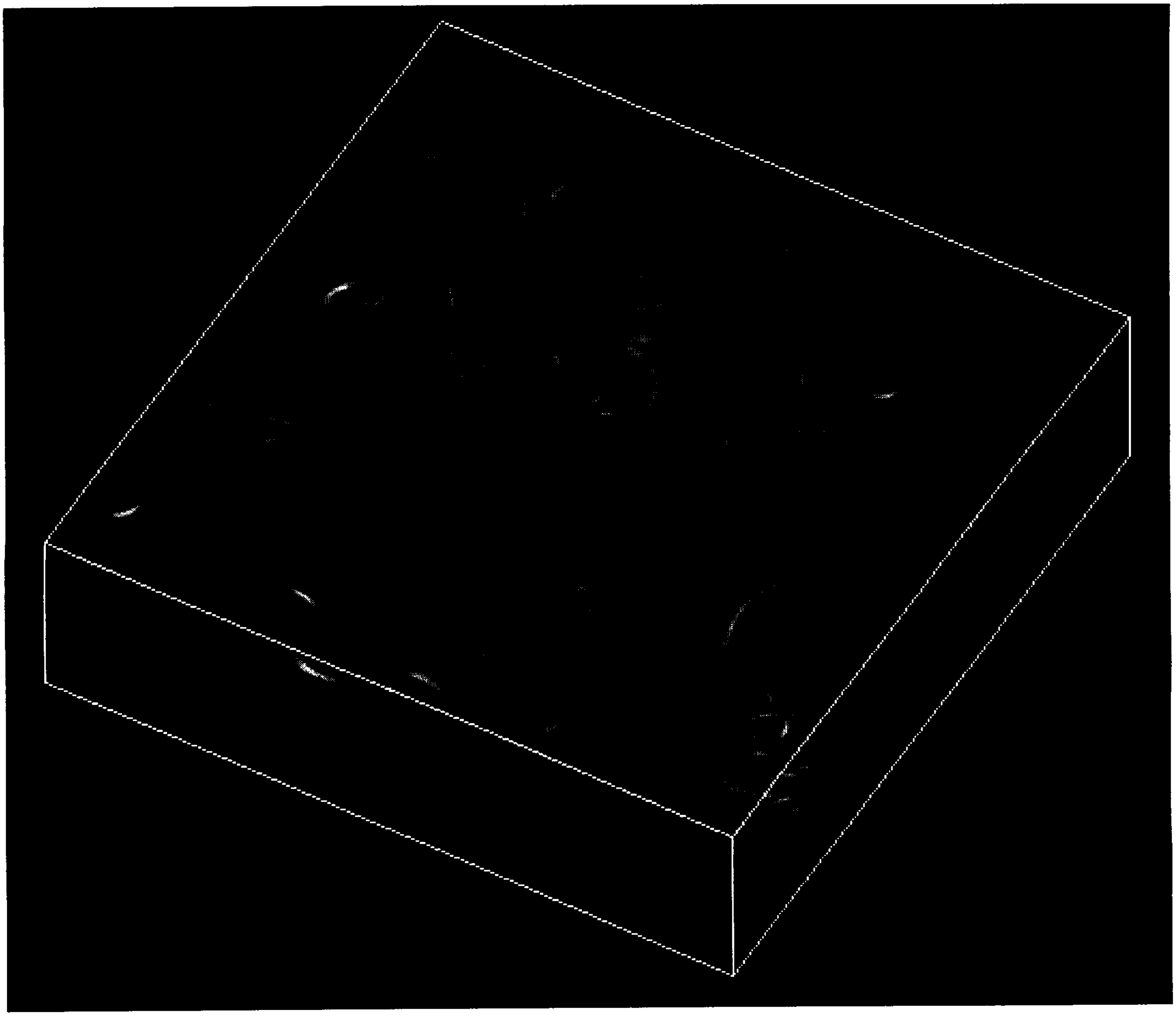
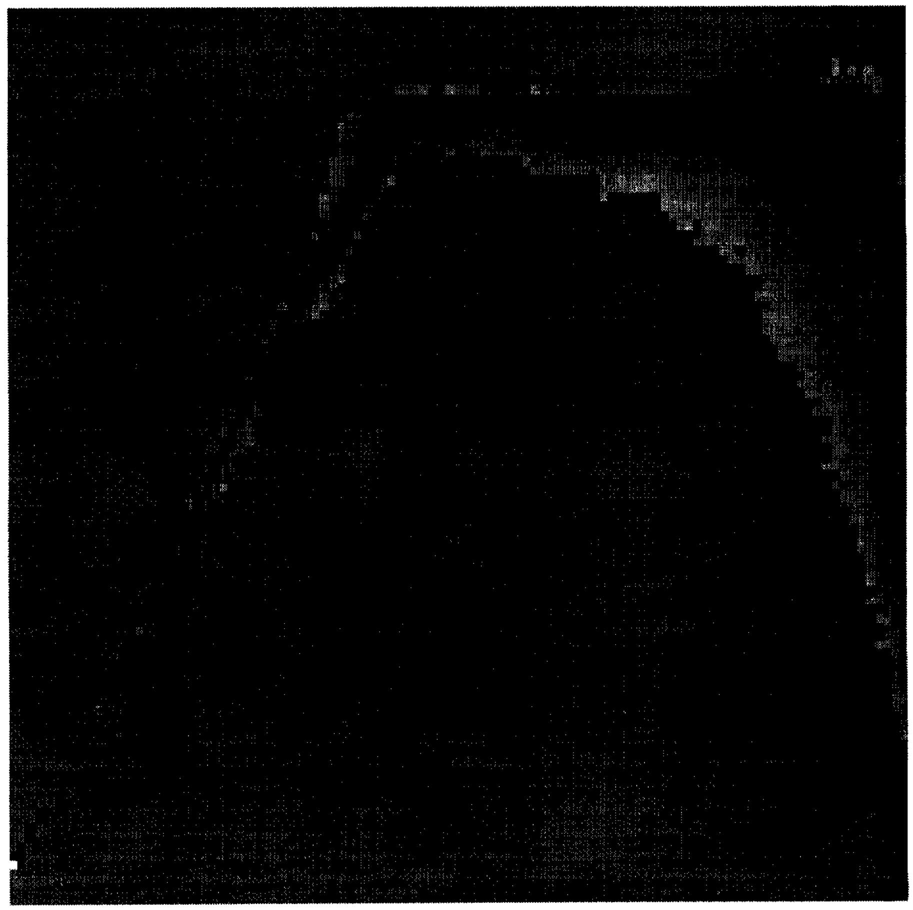


Figure 1: Vortex tubes viewed from above the surface in a realistic simulation of convection near the solar surface. The dark areas are free of significant vorticity and correspond to the hot, upflowing, bright granules. The vortex tubes are concentrated in the cool, downflowing, dark intergranule lanes. The twisting of these vortices about one another shows the turbulent nature of the flow.

Entropy



Height

Figure 2: Histogram of entropy fluctuations as a function of depth. The fluctuations decrease rapidly with depth. Most of the fluid is in upflows and its entropy is close to the mean. Fluctuations in ascending material are rapidly washed out by the diverging flow. Entropy of descending material increases with depth because of heating by radiation and entrainment of overturning ascending material.